# Estimating climate change effects on installation energy use

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# Introduction and summary

## Background

In its 2009 report [1], the U.S. Global Change Research Program stated that climate change impacts are already being observed across the United States, and ecosystems and society are going to have to adapt to the ongoing changes in climate. As a result, Executive Order 13514 of October 5, 2009, [2] directed the formation of the Interagency Climate Change Adaptation Task Force, jointly chaired by the Council on Environmental Quality, the Office of Science and Technology Policy, and the National Oceanic and Atmospheric Administration, and staffed with representatives from more than 20 federal agencies, including the Department of Defense (DOD). The task force recently recommended that the federal government expand and strengthen the nation's capacity to prepare for climate change. The task force further recommended that federal agencies make adaptation a standard part of agency planning [3].

Following the recommendations of the task force, as well as direction from the National Intelligence Assessment on the National Security Implications of Climate Change [4] and the Quadrennial Defense Review [5], DOD is now beginning to develop policies to ensure that climate change is properly accounted for in the department's infrastructure planning process.

Many aspects of installation infrastructure and management are subject to the effects of climate change. The challenge that is discussed most often is sea level rise and its obvious implications for coastal installations. Drought and its implications for water supply are also often discussed, as are the increase in severity of hurricanes and tropical storms and the resulting flooding and damage to structures. In this memo, we look at an obvious but seldom discussed implication of climate change for installation managers: rising temperatures and their implications for installation energy use.

# Procedure

We downscaled large regional-scale climate change forecasts to forecasts of temperature change for the immediate areas of military installations. Based on these expected temperature changes, we estimated how installation energy demand for heating and cooling may change. We considered two climate change scenarios: the median and 75th percentile predicted temperature changes given in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (FAR) [6]. We consider temperature change in 2040 relative to the 1995–2011 17-year mean. We examine four large DOD installations—one from each service and covering each of the three IPCC FAR predicted climate areas:

- Tinker Air Force Base (AFB)

- Naval Station (NAVSTA) Norfolk

- Camp Pendleton

- Fort Bragg

We present two estimates of future energy use.

First, we consider heating fuels and electricity separately. Energy use for heating and cooling are driven by heating degree days (HDD) and cooling degree days (CDD), which reflect the difference between a daily average temperature and the "energy neutral" temperature of 65 $^{\circ}$F. We use IPCC temperature forecasts for various areas of the United States to estimate expected annual HDD and CDD for 2040, and we use relationships between energy use and heating/cooling degree days at DOD installations within the continental United States (CONUS) determined in a previous study [8] to estimate how these climate changes may drive changes in energy demand at installations. We separately consider electricity use (predominately used for cooling) and nonelectric fuel use (predominately used for heating) because increasing temperatures will obviously increase the former and decrease the latter.

Next we attempt to estimate an overall net change in energy use at DOD installations resulting from climate change. For this, we use a

recently published study of temperature-energy relationships that accounts for the nonlinear nature of the temperature-energy response and the large effect of extreme temperatures, but is based on data for U.S. residential energy use rather than DOD installations.

# Summary of findings

## Climate (HDD and CDD)

The IPCC FAR forecasts temperature changes for three areas within CONUS: East, Central, and West. Predicted temperature change varies by season, but overall it is between about +2.5 and +3.5 $^\circ$F for 2040, where the plus sign indicates warming. This will cause increases in CDD and decreases in HDD.

Changes in cooling degree days will be significant. Under the expected (median) temperature change scenario, average annual CDD will increase by about 22 percent at Tinker, 67 percent at Camp Pendleton, 23 percent at NAVSTA Norfolk, and 24 percent at Fort Bragg. Under the 75th percentile scenario, these changes will be 28, 89, 30, and 30 percent, respectively. Predicted changes (decreases) in HDD are somewhat smaller. Under the expected (median) temperature change scenario, average annual HDD will decrease by about 12 percent at Tinker, 36 percent at Camp Pendleton, 14 percent at NAVSTA Norfolk, and 15 percent at Ft. Bragg. Under the 75th percentile scenario, these changes will be 15, 42, 17, and 17 percent, respectively.

## Energy use

We estimate that:

- Electricity use will *increase* under the median climate change scenario as follows: 7 percent at Tinker, 20 percent at Camp Pendleton, 7 percent at NAVSTA Norfolk, and 7 percent at Fort Bragg. Under the 75th percentile scenario, these changes will be 8, 27, 9, and 9 percent, respectively.

- Heating fuel use will *decrease* under the median climate change scenario as follows: 6 percent at Tinker, 18 percent at Camp

Pendleton, 7 percent at NAVSTA Norfolk, and 7 percent at Fort Bragg. Under the 75th percentile scenario, these changes will be 8, 21, 9, and 9 percent, respectively.

The foregoing results for electricity and heating fuels are based on linear models of the response of energy use to changes in degree days. A nonlinear model that accounts for the effect of extreme temperatures suggests that the overall net change in energy use to 2040 will be between 4 and 6 percent under the median scenario and between 5 and 8 percent under the 75th percentile scenario.

Of the four installations examined, Camp Pendleton shows the largest changes in expected energy use. This is because it is in an area of mild climate, with relatively low current demand for heating or cooling. Thus, the change in temperature of a few degrees in either direction will have a large relative effect. In terms of absolute change in energy use (MBTU per year), the predicted changes at Camp Pendleton are approximately equal to those at Tinker and Fort Bragg. NAVSTA Norfolk shows the lowest absolute changes because of its lower current energy use than Tinker and Fort Bragg, and its lower relative change in climate than Camp Pendleton.

## Conclusions

Climate change has the potential to significantly affect installation energy use. Installation planners need to account for this—not only for the potential increase in energy costs but also for its implications for building design and heating and cooling systems.

The methods used here provide a useful framework for installation managers to use. Simple downscaling procedures such as those applied here could be used to examine impacts of changes in energy use at all installations. At a minimum, installation planners should include consideration of how their HDD and CDD are likely to change in future years. Assuming that buildings are designed and constructed differently for different locations (climates), downscaled climate predictions such as those done here would allow installation infrastructure planners to examine circumstances in which an installation in location "x" in year 2040 will face a climate like that of location "y" today and to plan accordingly.

# Suggestions for further research

The climate change calculations presented here account for shifting mean temperatures but do not address the more serious issue of the expected increase in extreme temperature events. A further study could treat the temperatures in 2040 as random variables to determine probability distributions of predicted temperatures and thus probability distributions of changes in heating and cooling requirements and the resulting probability distributions of changes in energy use. This would allow installation planners to weigh risks when making investment decisions concerning expected energy costs or heating/cooling infrastructure.

The information available for this study, relating changes in energy use to changes in temperature, consisted of two types. For separate estimates of electricity and heating fuel demands, we found linear response coefficients based on a previous CNA study of DOD installations [7]. For overall net energy use, we found a nonlinear model that accounted for the greater effects of extreme temperatures, based on an academic study of residential energy use. We would like to investigate similar nonlinear response models using data from DOD installations. A further study could use observed temperature data to estimate the annual number of days in various temperature bins as well as data on installation energy use to develop nonlinear response models for the temperature-energy use relationship at DOD installations. Such a nonlinear response model may allow us to more accurately forecast DOD electricity and heating fuel needs.

We considered only four installations. Many more installations, in various climate zones within CONUS and outside CONUS, should be considered.

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# Expected temperature changes

We examine four large DOD installations that represent each service and cover all three IPCC FAR predicted climate areas. Table 1 summarizes the installations considered.

Table 1.   Installations considered

| Installation | Service | Temperature data used | IPCC FAR U.S. climate area |
|---|---|---|---|
| Tinker Air Force Base | Air Force | Oklahoma City, OK | Central |
| Naval Station Norfolk | Navy | Norfolk, VA | East |
| Camp Pendleton | Marines | San Diego, CA | West |
| Fort Bragg | Army | Raleigh, NC | East |

# Current temperatures

For current climate, we used daily temperature data available from the National Climatic Data Center, covering 1995 through 2011 [8]. In a very few instances, a short (generally 1-day) gap in the daily data existed, so in those cases we interpolated to fill the gaps. For each of the four 17-year (6,209-day) temperature series used, we interpolated in 15 days. For each day, we calculated heating degree days (HDD) and cooling degree days (CDD) as the difference between the daily mean temperature and 65 °F. If the daily mean temperature is below 65 °F, HDD are obtained; if it is above 65 °F, CDD are obtained. A daily mean temperature of exactly 65 °F is assumed to require neither heating nor cooling, so it would produce zero degree days.

In table 2, we summarize the temperature climates at the four installations.

Table 2.   Heating and cooling degree days, 1995-2011 17-year means

| Month | Tinker HDD | Tinker CDD | Pendleton HDD | Pendleton CDD | NAVSTA Norfolk HDD | NAVSTA Norfolk CDD | Fort Bragg HDD | Fort Bragg CDD |
|---|---|---|---|---|---|---|---|---|
| January | 826 | 0 | 244 | 2 | 726 | 1 | 736 | 0 |
| February | 624 | 0 | 210 | 1 | 617 | 1 | 596 | 1 |
| March | 442 | 9 | 182 | 5 | 476 | 6 | 427 | 8 |
| April | 182 | 41 | 135 | 11 | 220 | 38 | 183 | 48 |
| May | 40 | 175 | 71 | 21 | 64 | 122 | 51 | 140 |
| June | 1 | 371 | 25 | 36 | 4 | 322 | 4 | 332 |
| July | 0 | 546 | 3 | 119 | 0 | 443 | 0 | 431 |
| August | 0 | 524 | 1 | 165 | 0 | 414 | 0 | 404 |
| September | 17 | 258 | 1 | 134 | 3 | 240 | 17 | 204 |
| October | 158 | 53 | 21 | 50 | 122 | 58 | 181 | 42 |
| November | 438 | 4 | 120 | 11 | 364 | 6 | 422 | 6 |
| December | 779 | 0 | 258 | 0 | 620 | 2 | 683 | 1 |
| Total | 3507 | 1981 | 1271 | 555 | 3217 | 1653 | 3299 | 1615 |

# Changes to year 2040

The Intergovernmental Panel on Climate Change (IPCC) provides ensemble temperature change predictions for CONUS by season and region (East, to 85 degrees west longitude; Central, from 85 to 103 degrees longitude, and West, longitude greater than 103 degrees) [6]. Table 3 (taken from [6]) shows the median and 75th percentile seasonal temperature increase predictions for the three regions of the United States described above. The temperature change refers to a 100-year change from the 1980–1999 mean to the predicted 2080–2099 mean.

Table 3.   IPCC predicted temperature increases from 1980–1999 to 2080–2099 ($^O$C), from [6]

| Quarter | East Median | East 75th per. | Central Median | Central 75th per. | West Median | West 75th per. |
|---|---|---|---|---|---|---|
| December–February | 3.8 | 4.6 | 3.5 | 4.2 | 3.6 | 4.4 |
| March– May | 3.5 | 3.9 | 3.3 | 3.9 | 3.1 | 3.4 |
| June–August | 3.3 | 4.3 | 4.1 | 5.1 | 3.8 | 4.7 |
| September–November | 3.5 | 4.4 | 3.5 | 4.6 | 3.1 | 4.5 |

We scaled the temperature changes in table 3 to a change over the 37-year period from 2003 (2003 is the mean of our 17-year 1995–2011 data) to 2040 as follows. We assumed the changes given in table 3 occurred linearly over the 100-year period given (a reasonable assumption, according to [6]). We then multiplied the temperature changes given in table 3 by 0.37. Results are given in table 4, converted to degrees Fahrenheit.

Table 4.  Temperature increase, 2003–2040 ($^{o}$F)

| | East | | Central | | West | |
|---|---|---|---|---|---|---|
| Quarter | Median | 75$^{th}$ per. | Median | 75$^{th}$ per. | Median | 75$^{th}$ per. |
| December–February | 2.5 | 3.1 | 2.3 | 2.8 | 2.4 | 2.9 |
| March–May | 2.3 | 2.6 | 2.2 | 2.6 | 2.1 | 2.3 |
| June–August | 2.2 | 2.9 | 2.7 | 3.4 | 2.5 | 3.1 |
| September–November | 2.3 | 2.9 | 2.3 | 3.1 | 2.1 | 3.0 |

To convert these temperature changes to changes in average annual heating and cooling degree days, we added this temperature change to every day of the 1995–2011 period, recomputed the daily HDD and CDD values from this modified temperature record, and took annual means. Results are given in table 5 for the median and 75th percentile climate change scenarios.

Table 5.  Changes in annual mean HDD and CDD, 2003 to 2040

| | HDD | | | CDD | | |
|---|---|---|---|---|---|---|
| Installation | 2003 | 2040 | Change (%) | 2003 | 2040 | Change (%) |
| Median climate scenario | | | | | | |
| Tinker Air Force Base | 3,507 | 3,069 | -12.5 | 1,981 | 2,411 | 21.7 |
| Naval Station Norfolk | 3,217 | 2,753 | -14.4 | 1,653 | 2,038 | 23.3 |
| Camp Pendleton | 1,271 | 811 | -36.2 | 555 | 926 | 66.9 |
| Fort Bragg | 3,299 | 2,814 | -14.7 | 1,615 | 1,998 | 23.7 |
| 75th percentile climate scenario | | | | | | |
| Tinker Air Force Base | 3,507 | 2,969 | -15.4 | 1,981 | 2,530 | 27.7 |
| Naval Station Norfolk | 3,217 | 2,659 | -17.4 | 1,653 | 2,145 | 29.7 |
| Camp Pendleton | 1,271 | 733 | -42.3 | 555 | 1,049 | 89.0 |
| Fort Bragg | 3,299 | 2,736 | -17.1 | 1,615 | 2,102 | 30.2 |

Overall, changes in both HDD and CDD are significant for all four installations, for both the median and 75th percentile climate scenarios. Because all four installations show more current (2003) HDD than CDD, the percentage changes in CDD are larger than the percentage changes in HDD at all four. Of the four installations examined, Camp Pendleton shows the largest percentage changes in both HDD and CDD. This is because Camp Pendleton currently experiences a relatively mild climate, with low demand for heating or cooling. Thus, the change of a few degrees of temperature in either direction will have a large relative effect.

In addition to examining annual mean changes, we looked to see if the shape of the seasonal distributions of degree days changes much from 2003 to 2040. That is, we looked to see if the expected temperature increases in 2040 would result in additional months in which heating would not be required or additional months in which cooling would be required. We found this not to be the case. Overall, for the four installations considered, the temperature changes predicted for 2040 do not significantly shift the shape of the annual HDD or CDD distributions. For the most part, there is not a need for cooling in 2040 in months in which cooling was not needed in the baseline years. Similarly, the distribution of months in which heating is needed does not significantly change. Figures 1 and 2 show an example of this result for Camp Pendleton HDD and CDD, respectively. The only difference we see is that, for the 75th percentile temperature scenario, the slight current need for heating at Camp Pendleton just about disappears in June, July, and October.

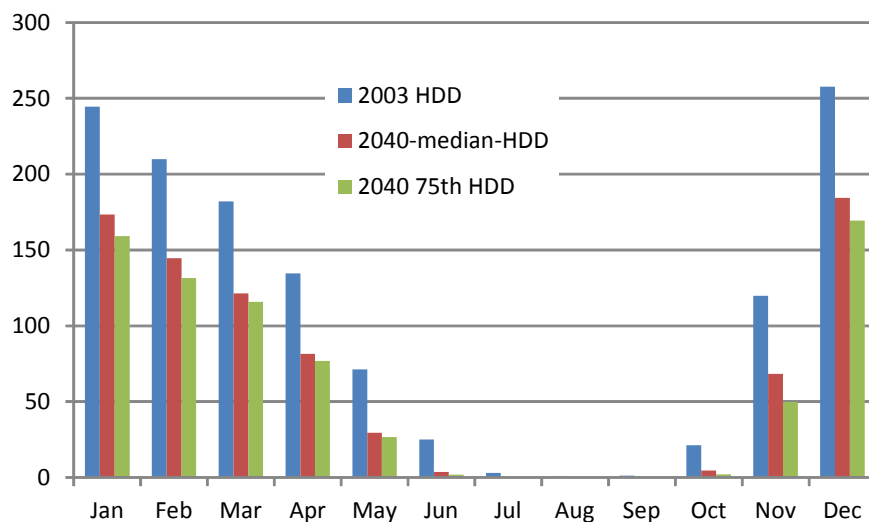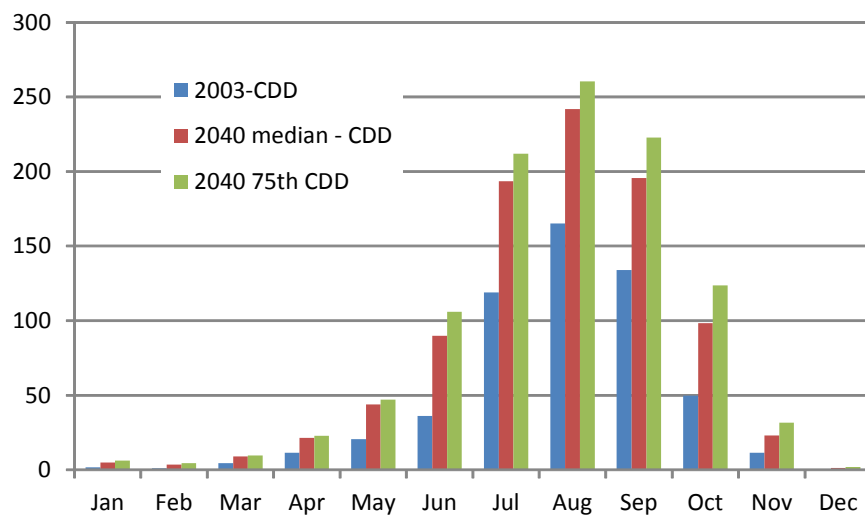Figure 1.    Monthly distribution of HDD, Camp Pendleton



Figure 2.   Monthly distribution of CDD, Camp Pendleton

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# Expected changes in energy use

## Electricity and nonelectric heating fuel: a linear model

We now consider how the changes in HDD and CDD discussed in the previous section can affect energy use. From the highest level viewpoint, one can assume that an increasing temperature will be roughly energy neutral since the increased demand for cooling will be offset by the decreased demand for heating. However, heating and cooling produce different energy demands, so, from the point of view of installation management, it is useful to look at each separately.

In a 2011 study [7], CNA estimated that a 10-percent change in CDD produces a 3-percent change in electricity use, and a 10-percent change in HDD produces a 5-percent change in heating fuel use. These changes are in terms of energy use per square foot of building space. Based on these simple relationships, we estimate the likely changes in energy use from 2003 to 2040 in figures 3 and 4.

Under the median climate change scenario, heating fuel use will decrease by 5 to 10 percent at Tinker AFB, NAVSTA Norfolk, and Fort Bragg and by about 18 percent at Camp Pendleton. Under the 75th percentile scenario, the decreases will be greater in all cases—with the decrease being over 20 percent at Camp Pendleton. The expected increases in electricity use show a similar pattern; the projected increase at Camp Pendleton is over 26 percent in the 75th percentile scenario.

We noted earlier that Camp Pendleton shows the largest relative changes in HDD and CDD because of its stable, mild climate. To understand which installations (in what types of climates) are expected to show the greatest changes in energy use as climate changes (generally warms over most of CONUS), we examined the relationship between variability in current climate and expected

Figure 3.    Percentage change in heating fuel use, 2003–2040
            (negative change indicates decrease)
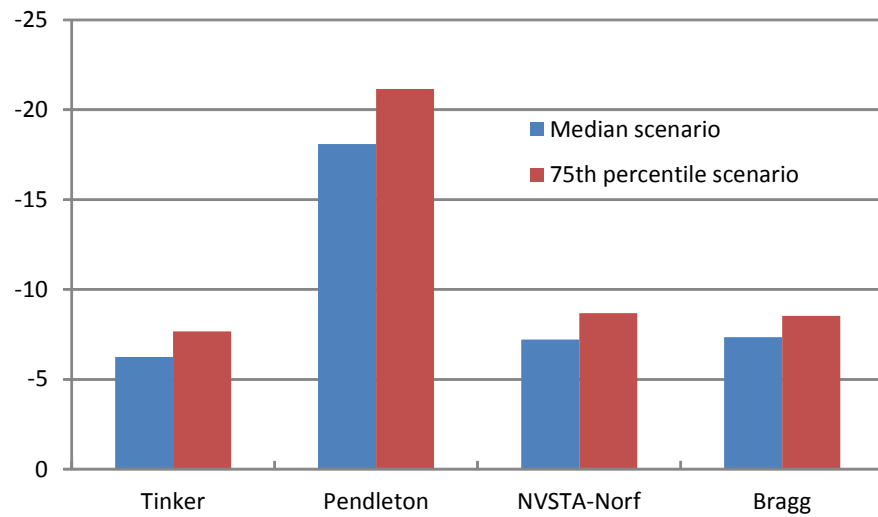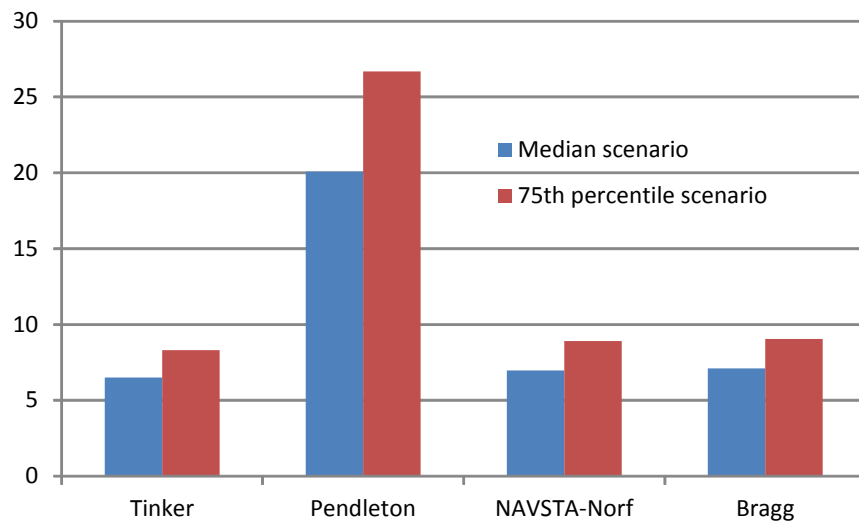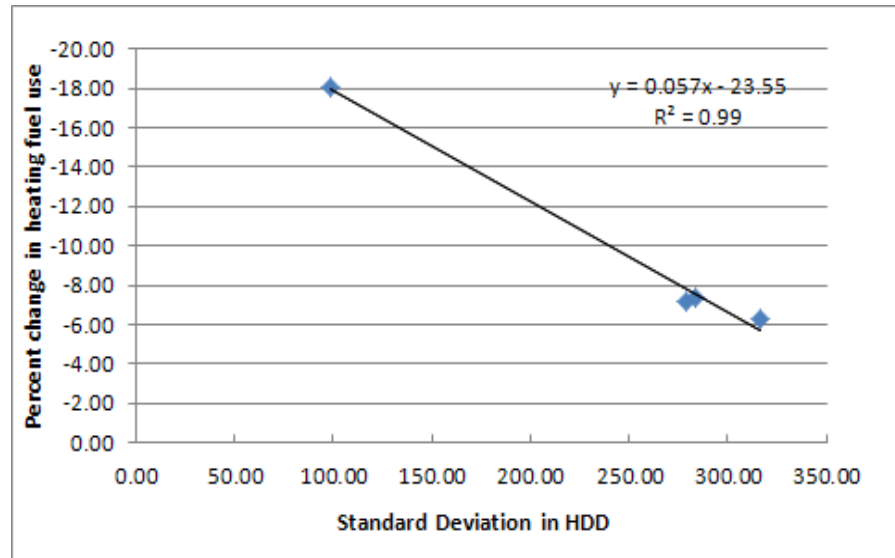


Figure 4.    Percentage change in electricity use, 2003–2040
            (positive change indicates increase)

change in energy use, using results from the four installations examined here. Results are shown in figures 5 and 6.

Figure 5.  Predicted percentage change in heating fuel use in 2040 vs. standard deviation in 2003–2011 monthly mean HDD



Figures 5 and 6 show the relationship between standard deviation in current (1995–2011) monthly HDD and CDD, respectively, and the expected changes in the corresponding energy use to 2040. The standard deviations in degree days were computed by taking the monthly means for the 1995–2003 17-year period, and then taking the standard deviation across the 12 monthly means. In both the HDD and CDD cases, the magnitude of the percentage change in energy use decreases with increasing standard deviation in degree days, with a linear relationship providing a very good fit in both cases. This suggests that, for the purposes of installation planning, installations in areas of relatively mild climate with low heating and cooling needs will experience the largest relative changes in their heating and cooling needs as climate changes—given the linear relationships between HDD or CDD and energy needs used in this analysis. A further study could examine the implications of nonlinear relationships between degree days and energy use.

Figure 6.   Predicted percentage change in electricity use in 2040 vs.
standard deviation in 2003–2011 monthly mean CDD
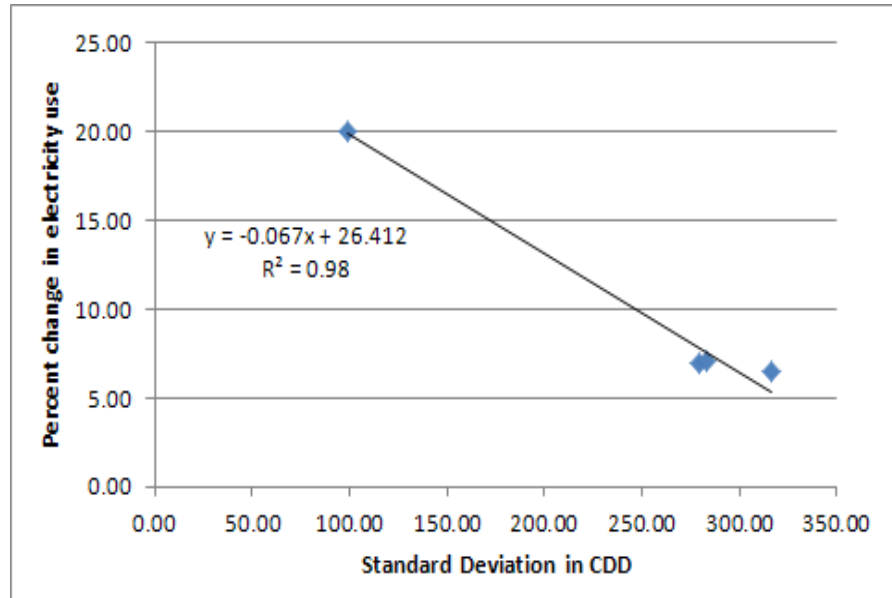


Figures 3 and 4 show the change in energy use expected in 2040 on a relative (percentage) basis. Table 6 shows the expected energy changes in an absolute sense: the increase in MBTU per year resulting from the given changes in temperature. Negative values indicate a decrease in energy use. In terms of absolute changes, Camp Pendleton is roughly on par with Tinker AFB and Fort Bragg because of its lower current energy demand. The largest changes are at NAVSTA Norfolk.

Table 6.   Expected changes in electricity and heating fuel use, MBTU/year

| Installation | Change in heating fuels (MBTU/year) | | Change in electricity (MBTU/year) | |
|---|---|---|---|---|
| | Median scenario | 75th percentile scenario | Median scenario | 75th percentile scenario |
| Tinker Air Force Base | -119,243 | -146,584 | 100,145 | 127,808 |
| Camp Pendleton | -105,867 | -123,895 | 103,193 | 137,200 |
| Fort Bragg | -100,796 | -117,016 | 128,421 | 163,358 |
| Naval Station Norfolk | -56,781 | -68,259 | 59,841 | 76,473 |

# Net energy use: a nonlinear model

In the previous section, we looked separately at heating and cooling energy use. The relationships between HDD or CDD and energy use were based on regression analyses given in [7], and they assume a linear response. Recent academic literature, however, suggests that the overall net change in energy use resulting from changes in climate may be more complicated (and nonlinear) and driven more by extreme temperatures [9]. Simply stated, the energy requirements associated with a temperature increase from 65 to 66 $^{\circ}$F may be very different from those associated with a rise from 95 to 96 $^{\circ}$F.

Our linear model of the response of energy use to degree days suggests that the overall change in energy use may be somewhat neutral because increased cooling requirements and decreased heating requirements will largely cancel. This may be an underestimate of the net overall effect of climate change on total energy use, due to nonlinear effects of temperature extremes. To examine this, we now use a nonlinear energy-temperature response model described in [9].

The model described in [9] is based on residential energy use in the United States over the 1968–2002 period. It calculates the fractional increase in annual energy use for each additional day in which the average temperature is in a particular 10-degree-wide bin, with the energy response equal to 0 for the bin in the range of 50 to 60 $^{\circ}$F. Table 7 shows the temperature-energy responses from [9]. For example, each additional day in the bin ranging from 80 to 90 $^{\circ}$F raises annual energy use by 0.17 percent; each additional day in the >90 $^{\circ}$F

bin raises it .37 percent. At the other temperature extreme, each day in the <10 $^{\circ}$F bin raises annual energy use .32 percent.

We used our downscaled daily temperature forecasts to estimate distributions of daily temperatures for each of the four installations for the two 2040 temperature change scenarios, and we compared these with the distribution based on the 1995–2011 mean. We then used the temperature response coefficients shown in table 7 to estimate the effect on energy use. Results are given in table 8. Overall energy use (the net of decreased energy use for heating and increased energy use for cooling) is likely to increase between 4.0 and 5.7 percent under the median temperature scenario and between 4.9 and 7.5 percent under the 75th percentile scenario.

Table 7.  Energy use vs. daily temperature, from [9]

| Temperature bin ($^{\circ}$F) | Percentage change in annual energy use |
|---|---|
| <10 | .32 |
| 10–20 | .19 |
| 20–30 | .22 |
| 30–40 | .12 |
| 40–50 | .08 |
| 50–60 | 0 |
| 60–70 | .01 |
| 70–80 | .03 |
| 80–90 | .17 |
| >90 | .37 |

Table 8.  Net change in energy use, nonlinear model

| | Net change (percentage) | |
| | Median temperature scenario | 75$^{th}$ percentile temperature scenario |
| Installation | | |
|---|---|---|
| Tinker Air Force Base | 4.0 | 4.9 |
| Naval Station Norfolk | 4.4 | 5.8 |
| Camp Pendleton | 5.7 | 7.5 |
| Fort Bragg | 4.0 | 5.5 |

The largest change is observed at Camp Pendleton. The reason for this is seen by examining figure 7, which shows the distribution of daily temperature in each of the bins. Going from the base case to the 2040 75th percentile scenario, predicted climate change results in roughly equal numbers of days leaving the bin of 60–70 °F and going to the bin of 80–90 °F. However, each day in the bin of 60–70 °F produces a change in energy use of .01 percent, while each day in the bin of 80–90 °F produces a change in energy use of .37 percent. Thus, the increase in the number of (relatively) very hot days outweighs the decrease in the number of moderately hot days. This behavior holds for the most part for all four installations examined. The overall change in energy use is significantly greater than what would be expected under the assumption of "heating needs and cooling needs cancelling out" because we see the movement of a few days into the very highest temperature bins more than making up for the movements of temperatures around the more moderate temperature bins. An interesting follow-on study could examine some installations in very cold climates to see how shifting the temperature distribution out of the extremely cold bins into more moderate bins (where the temperature-energy response is smaller) plays out in terms of overall energy use.

Figure 7.   Distribution of daily temperatures, Camp Pendleton
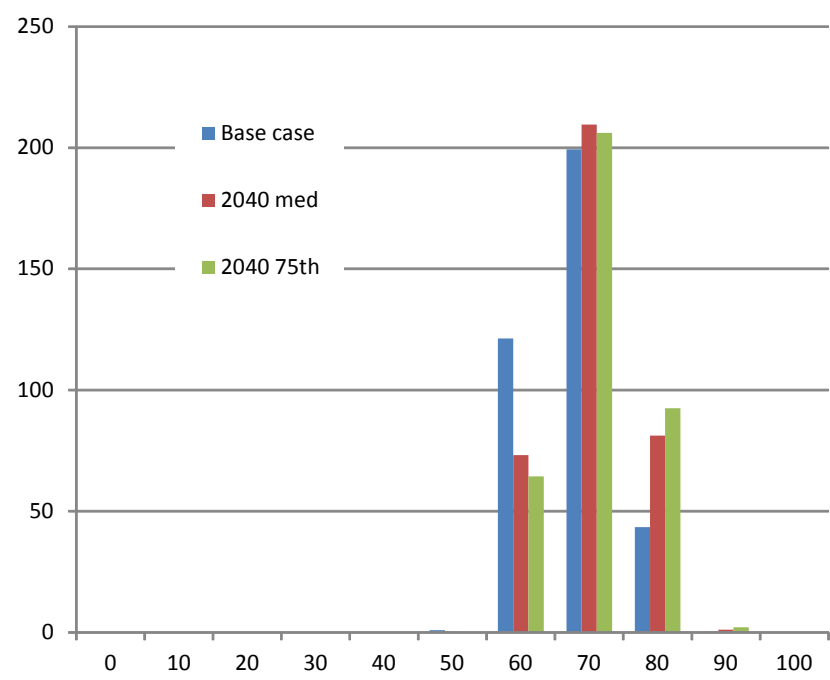
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